Van der Waals Correction to Nuclear Fusion by Mechanical Adiabatic Compression of a Dense Plasma

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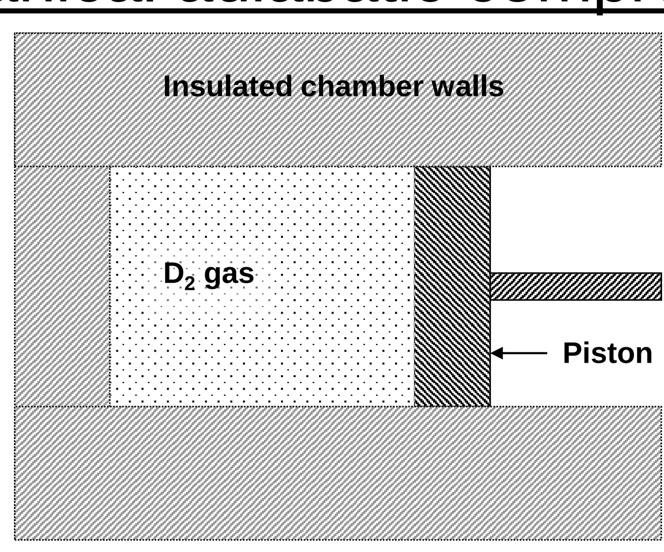
Abstract

We consider fusion processes initiated by the rapid adiabatic compression by a piston of a deuterium plasma contained in a well-insulated chamber. To exploit the n^2 factor in the fusion reaction rate, we consider one mole of deuterium which, at ambient temperature and pressure, provides a particle density of $\sim 10^{19}$ cm^{-3}. The reaction rate is enhanced by the application of magnetic and electric fields to reduce the number of degrees of freedom of the gas, thereby lowering its heat capacity and producing a higher temperature increase for a given energy input. Previous studies have shown that the combination of adiabatic operation, high particle density and reduced degrees of freedom can result in appreciable fusion rates at temperatures lower than those in magnetic confinement experiments. Prior work treated the deuterium gas as an ideal gas while the present work incorporates the corrections of a van der Waals gas. Both primary D-D reactions and secondary D-T reactions are considered. Conditions of energy-break-even and excess energy release were found at temperatures of the order of 10^6 K.

Proposed Method

Exploit n^2 factor and reduced degrees of freedom and perform under adiabatic conditions $\Rightarrow$ appreciable fusion rates at lower temperatures than in standard methods.

Mechanical adiabatic compression



Dense gas of D_2 undergoes adiabatic compression.
Rapid process - - explosively driven.
Well-insulated chamber – retain energy internally.

Starting conditions One mole D_2 at room P and T.

Apply compression. T increases.
D_2 molecules $\rightarrow$ D_2 atoms $\rightarrow$ D_2 atoms ionize
$\rightarrow$deuteron-electron plasma $\rightarrow$ Fusion of deuterons.

Assumptions. Make simplifying assumptions.
Reversible adiabatic compression
Apply equilibrium thermodynamics
Treat as *van der Waals* (vdW) gas: $(P + aN^2/V^2)(V - Nb) = RT$

Degrees of freedom γ = specific heat ratio
Relate to degrees of freedom f of the gas: $\gamma = (f + 2) / f$.
For monoatomic gas: f = 3
Deprive particles of freedom of motion $\Rightarrow$ larger T increase for a given energy input. Accomplish with
(1) External magnetic field(s)
(2) Electric discharge in direction of piston motion.
Also $\Rightarrow$ Pinch Effect.

Adiabatic compression of a vdW gas

$$T = T_0\left(\frac{V_0 - Nb}{V - Nb}\right)^{\gamma-1} = T_0\left(\frac{\beta(V_0 - Nb)}{V - \beta Nb}\right)^{2/f}$$

Work to compress a vdW gas

$$W = -\int_{V_0}^{V} PdV = \frac{NRT_0 f}{2}\left[\left(\frac{\beta(V_0 - Nb)}{V_0 - \beta Nb}\right)^{2/f} - \beta^{-2/f}\right] - \frac{aN^2}{V_0}(\beta - 1).$$

Nuclear fusion reactions

Primary: D + D $\rightarrow$ T + p + 4.03 MeV (T = tritium)
D + D $\rightarrow$ ^{3}He + n + 3.27 MeV

Secondary: D + T $\rightarrow$ α + n + 17.6 MeV
D + ^{3}H $\rightarrow$ α + p + 18.3 MeV

Energy release

Primary reactions occur with $\approx$ equal probability o
1st secondary reaction has much higher probability than 2nd.

Energy release in time Δt: $\Delta E = r\, Q\, V\, \Delta t$.
Q = av'g reaction energy release/reaction ; r = computed reaction rate

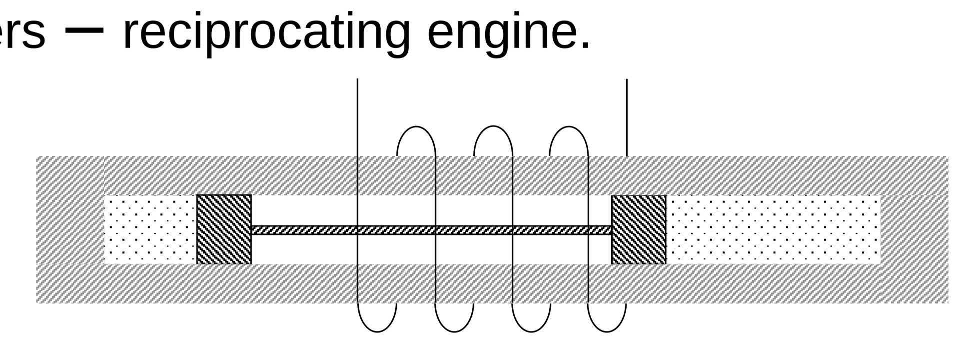
Simplification Assume fusion occurs only at maximum compression and that
One-half of deuterons react in primary D-D reactions;
Half of these result in formation of T;
These T react with the remaining D.

Calculate $\Delta E / W$ for β = 100, 125, . f = 3, 2, 1, Δt = 1 ms,
β = compression factor, f = no. degrees of freedom.
Best results
β = 100, f = 1: $\Delta E / W \approx 1$; $T \approx 5 \times 10^6$ K
β = 125, f = 1: $\Delta E / W \approx 50$; $T \approx 9 \times 10^6$ K.

Note: Energy Break-Even at $T \approx 5 \times 10^6$ K
Excess energy at $T \approx 9 \times 10^6$ K.

Applications

Single shot: Neutron source to initiate fission.
Multiple compressions in dual chambers — reciprocating engine.
Surround with coil to extract energy.



Summary and Conclusions

Exploited effects of n^2 factor and reduced degrees of freedom.
Adiabatic conditions $\Rightarrow$ energy retained internally.
Obtained energy break-even and excess energy at temperatures lower than in standard fusion methods

To be more realistic:
Not all input energy serves to compress gas.
Must consider particle losses via leakage.
Compensated by ignoring:
Pinch Effect.
Enhancements: Deuterated walls; Screening effects of electrons.

References

David W. Kraft, *Nuclear Fusion by Mechanical Adiabatic Compression of a Dense Plasma*, Proceedings of the 13th International Conference on Emerging Nuclear Energy Systems, ICENES 2007, İstanbul/Türkiye (3 – 8 June 2007) S. Şahin (Ed.) ISBN-978-975-01805-0-7.

David W. Kraft and Robert G. Butler, *Multistage Fusion Reaction Rates In An Adiabatically Compressed Plasma*, Transactions of Fusion Science and Technology **61**, 475 (2012).

David W. Kraft and Robert G. Butler, *Secondary Fusion Reactions in the Mechanical Adiabatic Compression of a Dense Plasma*, Presented at 16th International Conference on Emerging Energy Systems, ICENES 2013, Madrid, Spain (26-30 May, 2013) .